EEMS013

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

Integrated Framework to Quantify the Energy Impact of New Mobility Technologies from Individual Vehicles to Metropolitan Areas

Aymeric Rousseau, Phil Sharer, Sylvain Pagerit, Michael Juskiewicz, Paul Delaughter, Ram Vijayagopal, Namdoo Kim, Randy Weimer, Josh Auld, Dominik Karbowski, Vincent Freyermuth, Ehsan Islam, Ayman Moawad – ARGONNE NATIONAL LABORATORY

2018 DOE and Vehicle Technologies Annual Merit Review – June 20, 2017

Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

ENERGY EFFICIENT MOBILITY SYSTEMS PROGRAM INVESTIGATES

MOBILITY ENERGY PRODUCTIVITY

THROUGH FIVE EEMS ACTIVITY AREAS

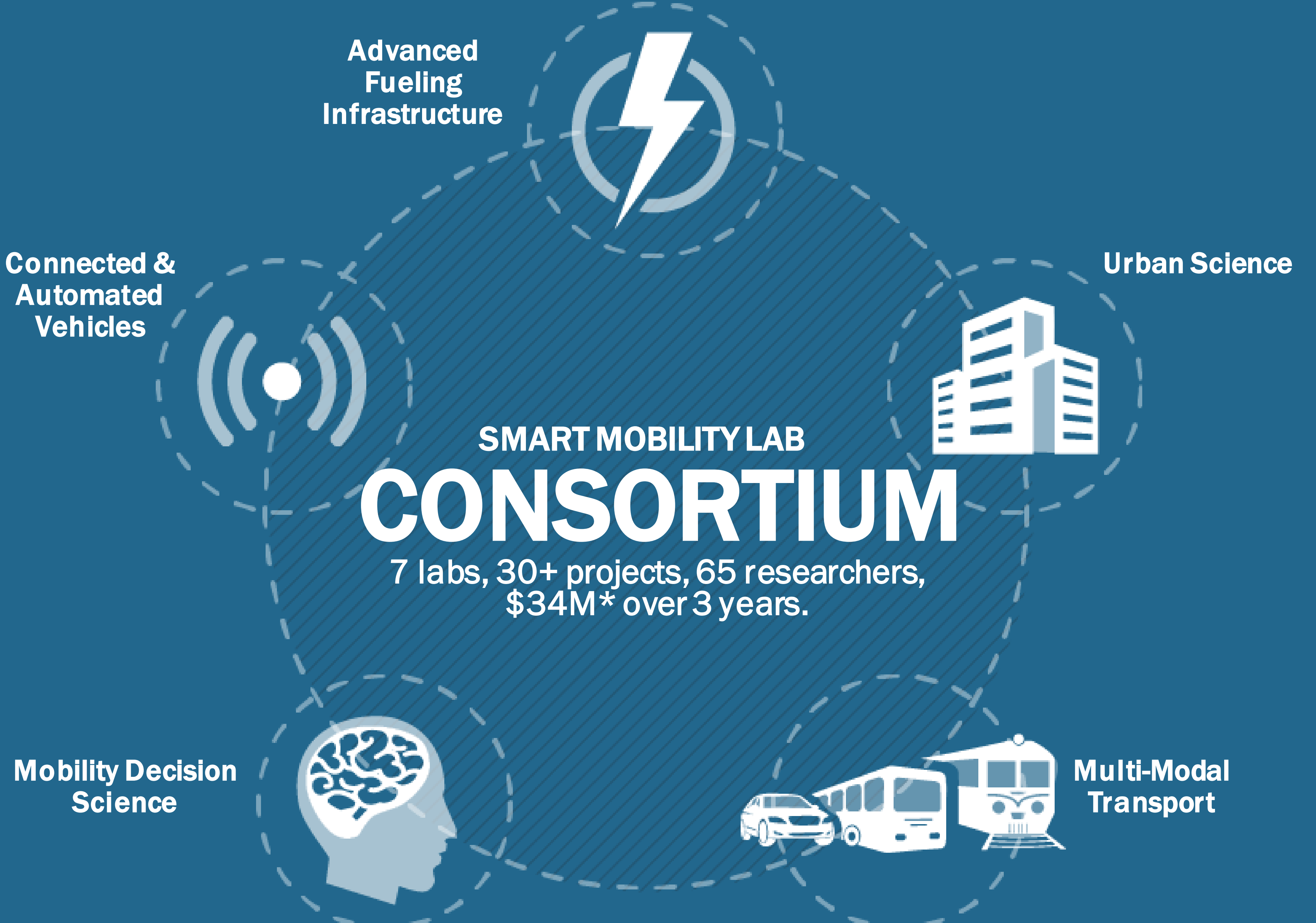
Advanced R&D Projects

Living Labs

Smart Mobility Lab Consortium

Core Evaluation & Simulation Tools

HPC4Mobility & Big Transportation Data Analytics



*Based on anticipated funding

Project Overview

Timeline	Barriers
• Project start date : Oct. 2015 • Project End date : Sep. 2018 • Percent complete : 95%	• Accelerate technology evaluation • Quickly and accurately assess the impact of new technologies with specific focus on Smart Mobility and vehicle electrification • Support technical requirement definition
Budget	**Partners**
• FY15-FY18 Funding: $4,500,000 • FY18 Funding : $1,500,000	• Argonne (Lead) • Users (OEMs, Nat Labs, Gov Agencies…) • MathWorks • 3rd party software companies

Relevance

Argonne simulation tools and results are used to support a very large number of VTO projects as well as organizations throughout the world to define R&D targets, evaluate the benefits of advanced technologies, provide R&D guidance…

- During the 2018 AMR, more than 26 projects are related to Autonomie:
  - More than 6 projects provided inputs to Autonomie (1)
  - More than 13 projects used Autonomie to perform studies (2)
  - More than 7 projects used results from Autonomie to perform further studies / analysis (3)
- Autonomie is also used to support ARPA-E NEXTCAR, Gate, DOT and DOD…

(1) EEMS023, EEMS030, EEMS033, EEMS041, EEMS045, EEMS049…

(2) EEMS001, EEMS016, EEMS017, EEMS029, EEMS031, EEMS032, EEMS055, VAN023, FT037, ELT189, ACS012, TI070, TI086…

(3) EEMS024, EEMS026, EEMS044, VAN017, VAN018, VAN019, VAN021…

Relevance - As Mobility and Technology Evolves, so Must Our Analytical Tools

Single Vehicle | **Corridor / Small Network** | **Entire Urban Area**

AUTONOMIE

- Funded by US DOE
- Vehicle energy consumption
- VTO performance requirements, cost and benefits
- Only commercial tool with vehicle level control
- Licensed to >250 companies, cross-agencies

RoadRunner

- Funded by US DOE
- Only system simulation of multi-vehicle and their environment focused on advanced control enabled by V2V, V2I…
- Uses Autonomie powertrain models

PTV VISSIM / Aimsun

- Commercial Tools
- Microscopic traffic flow simulation
- Focus on detailed traffic flow, control

POLARIS

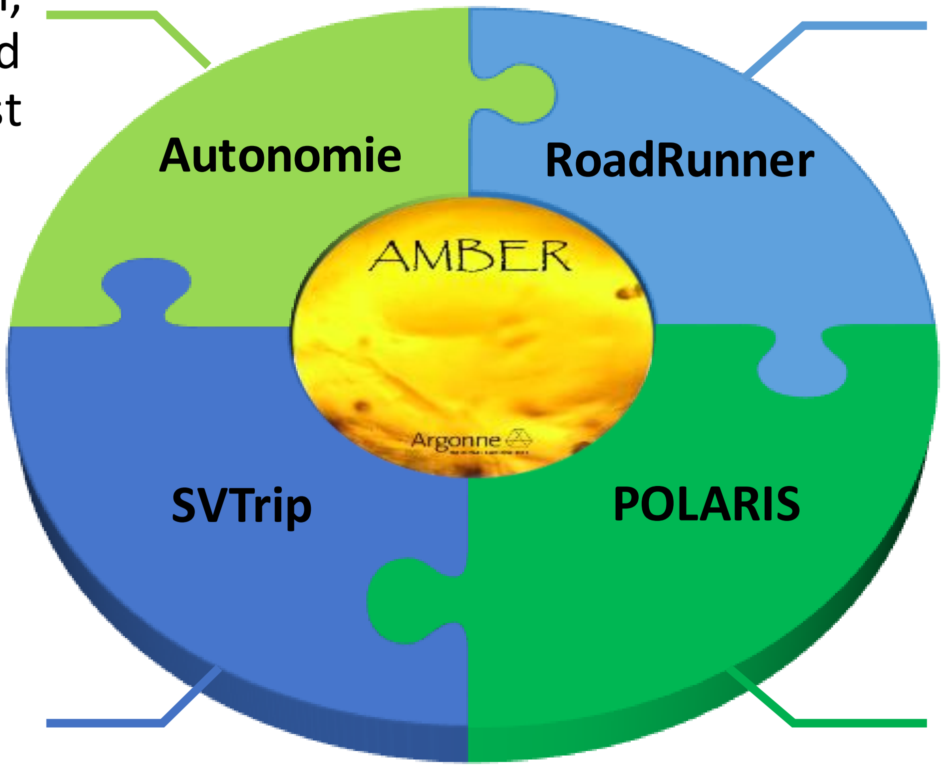
- Funded by US DOT/FHWA
- Agent-based mesoscopic traffic flow simulation
- Focus on traveler behavior, transport modes, technologies
- Use outputs from micro-simulation, Autonomie, GREET & MA3T

APPROACH

Approach – AMBER Workflow Manager

Accurate Vehicle Energy Consumption, Performance and Cost

Multi-Vehicle Simulation Environment for Control

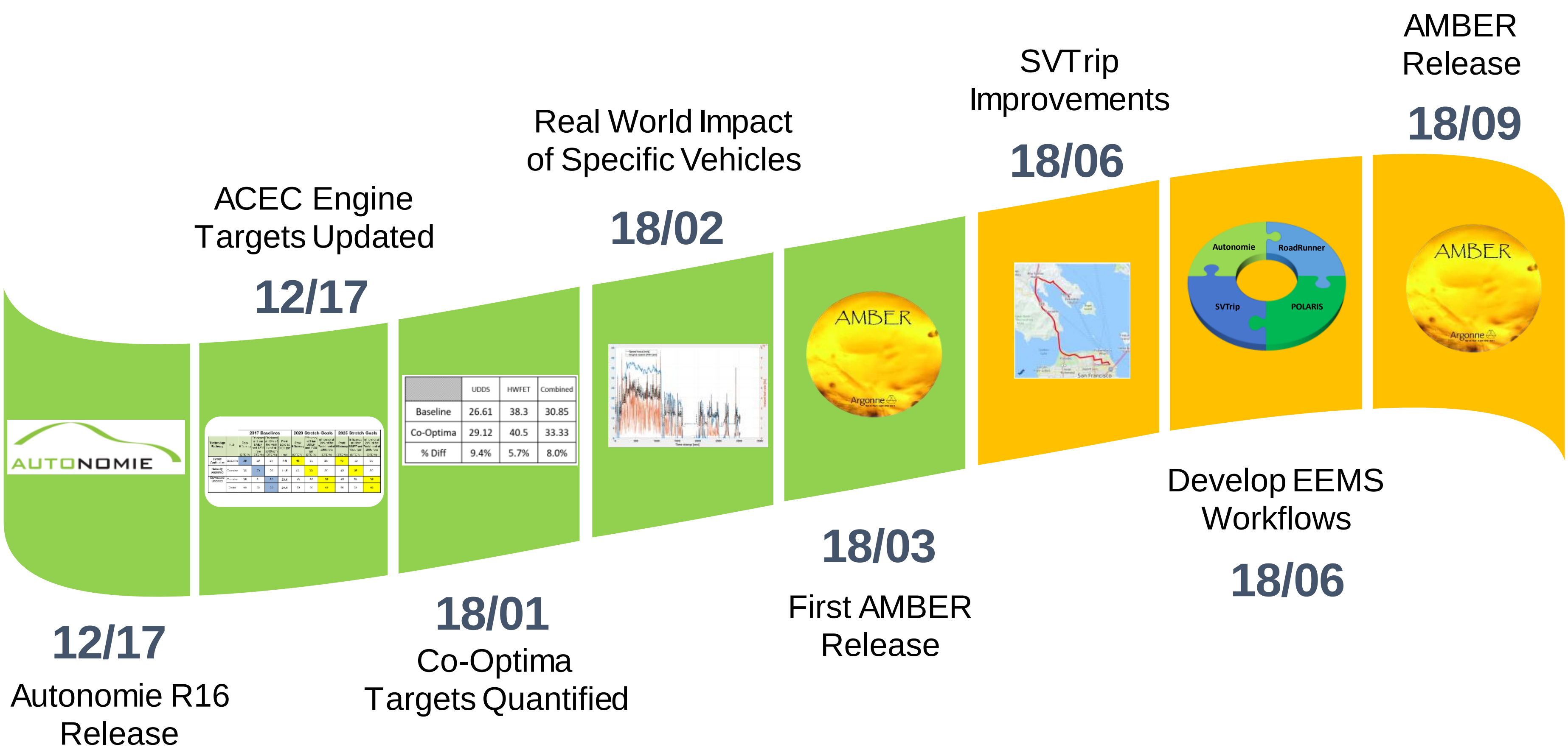


AMBER – New generation of workflow management

Stochastic Vehicle Trip Profile Prediction from GIS

Agent based transportation system simulation

Milestones



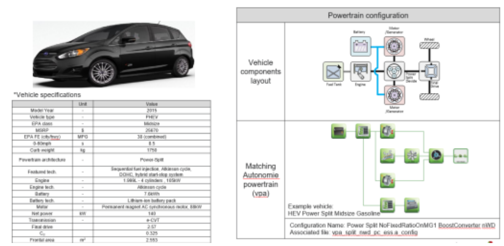
	UDDS	HWFET	Combined
Baseline	26.61	38.3	30.85
Co-Optima	29.12	40.5	33.33
% Diff	9.4%	5.7%	8.0%

TECHNICAL ACCOMPLISHMENTS

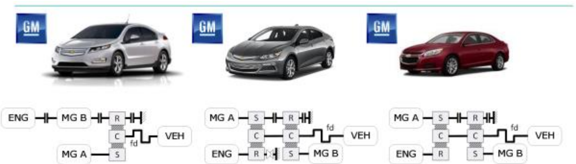
Developed Vehicle Models for Latest Technologies

Developed Individual Factsheets for >125 xEVs

PHEV – Ford C-MAX Energi Plug-in Hybrid (2015)



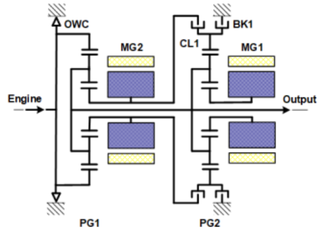
Analyzed Powertrain by OEM



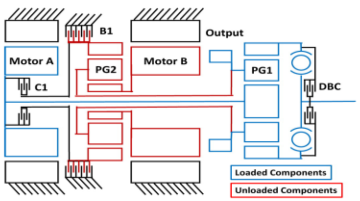
VOLT (MY2013-1gen)	VOLT (MY2016-2gen)	Malibu (MY2016)
1.4L, 62kW@4800rpm	1.5L, 75kW@5600rpm	1.8L, 91kW@5000rpm
Li-ion, 16.2kWh	Li-ion, 18.4kWh	Li-ion, 1.5kWh
55kW	48kW, PMSM	55kW
111kW	87kW, PMSM	76kW
35/40 mpg (City/Hwy)	43/42 mpg (City/Hwy)	48/45 mpg(City/Hwy)
9.0 s	7.1~7.8 s	7.4 s

Identified and Modeled New Powertrains

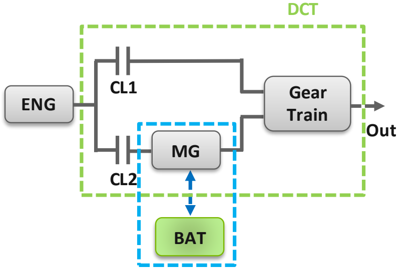
GM Voltec Gen II



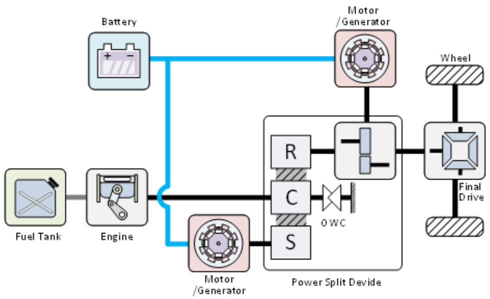
Malibu HEV



Honda DCT



Prius Prime



The GM Volt Gen II and the Prius Prime were validated using dynamometer data

Significantly Expanded Medium and Heavy Duty Vehicle Model Capabilities

- **Vehicles** : 13 vehicle classes representing the largest class/vocation combinations (>50% of US truck population)
  - Powertrains include conventional, ISG, HEV, PHEV, BEV & FCEV models to study the impact of technologies on MD & HD vehicles.
- **Large Number of Test Cycles :**
  - New EPA Test Procedure
  - Real world cycles from NREL database and other sources
- **Automated Sizing Logic :** No trade off in performance.
  - Match or better acceleration, cruise & grade speeds
  - BEV, FCEV range is based on daily driving distances derived from VIUS survey
  - Hybrids sized for fuel economy gains in ARB cycle
    - Cost vs. benefit analysis favors ISGs over HEVs
  - 100 miles selected as minimum range for Plug-In vehicles

Main Studies Highlights

Engine Targets Updated

Technology Pathway	Fuel	2017 Baselines: Peak Efficiency (BTE %)	2017 Baselines: Efficiency at 3 bar BMEP and 1300 rpm (BTE %)	2017 Baselines: Efficiency at 20% of the Peak Load at 2000 rpm (BTE %)	2017 Baselines: Peak Load at 2000 rpm (bar)	2020 Stretch Goals: Peak Efficiency (BTE %)	2020 Stretch Goals: Efficiency at 3 bar BMEP and 1300 rpm (BTE %)	2020 Stretch Goals: Efficiency at 20% of the Peak Load at 2000 rpm (BTE %)	2025 Stretch Goals: Peak Efficiency (BTE %)	2025 Stretch Goals: Efficiency at 3 bar BMEP and 1300 rpm (BTE %)	2025 Stretch Goals: Efficiency at 20% of the Peak Load at 2000 rpm (BTE %)
Hybrid Application	Gasoline	39	29	27	9.9	46	33	29	46	35	30
Naturally Aspirated	Gasoline	36	29	26	11.5	43	33	29	43	35	30
Downsized Boosted	Gasoline	38	31	32	20.8	43	35	35	43	38	36
	Diesel	40	32	33	24.4	50	36	40	50	39	42

Co-Optima Benefits Quantified

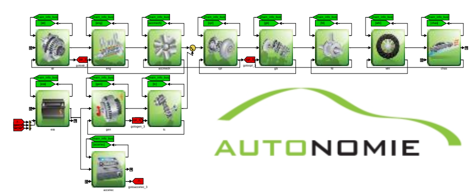
	UDDS	HWFET	Combined
Baseline	26.61	38.3	30.85
Co-Optima	29.12	40.5	33.33
% Diff	9.4%	5.7%	8.0%

Unadjusted mpgge

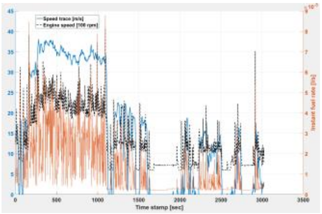
Real World Fuel Economy Prediction

UM Data
Vehicle Name
Time based
- Speed
- Fuel
- .....
- ....

Vehicle Technology Database



Data processing



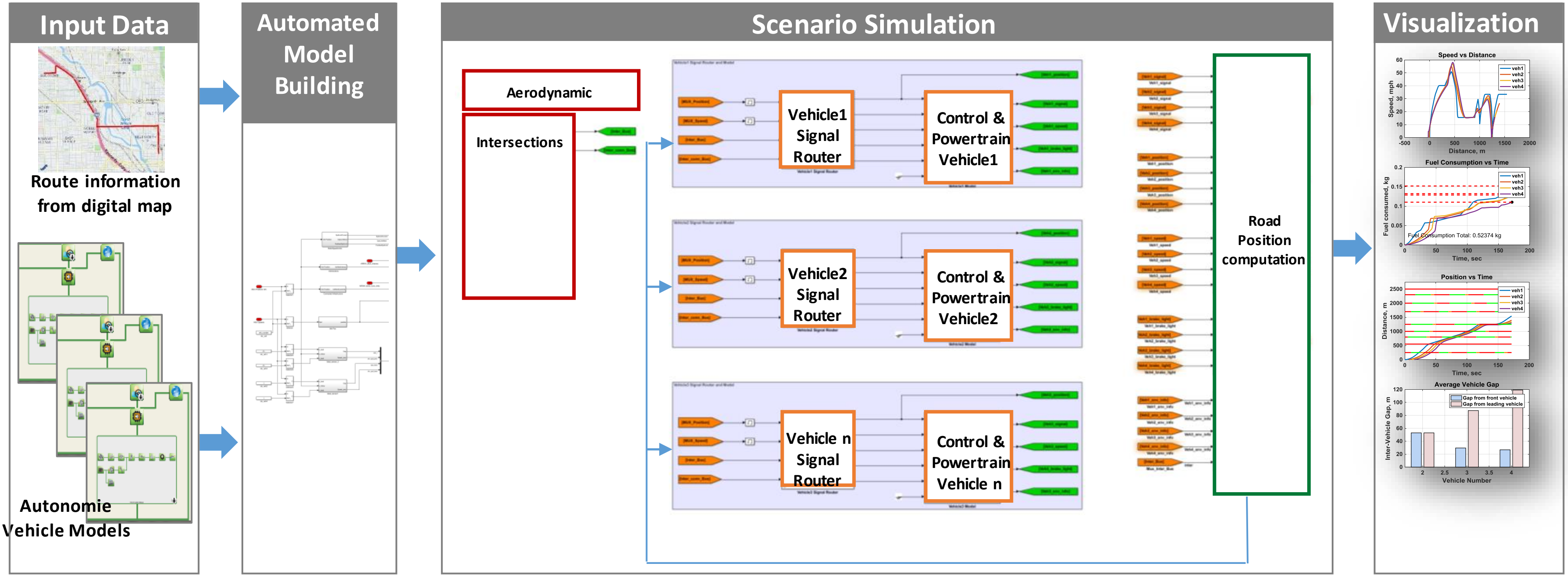
Specific Vehicle Comparison

2016 Chevrolet Traverse 2WD

Cycle id	Distance [km]	Real world fuel cons [l/100km]	Autonomie fuel cons [l/100km]	Diff [%]	Real world fuel eco [mpg]	Autonomie fuel eco [mpg]
cycle_190_92	5.4	0.6	0.5	8.9%	22.5	24.6
cycle_190_93	81.5	8.7	8.6	0.5%	22.1	22.2
cycle_190_94	79.2	8.6	8.5	1.4%	21.5	21.0

RoadRunner Process Automated

- Automated model building using Autonomie powertrain models
- Easy selection of scenarios through GIS
- Multi-vehicle analysis



POLARIS Capabilities Expanded

PolarisGL Visualizer

- Web-based results analysis
- Addition of many new layers (transit, energy, walk,…)
- Visualizing run comparisons
- polarisgl.es.anl.gov for an example case study

=> Objective is to share study results with research community

Network simulation controls

Name	Unit	Value
rng_type		DETERMINISTIC
node_control_flag		1
jam_density_constraints_enforced		True
maximum_flow_rate_constraints_enforced		True
merging_mode		PROPORTION_TO_DEMAND
use_realtime_travel_time_for_enroute_switching		False
pretrip_informed_market_share		0.75
realtime_informed_vehicle_market_share		0
information_compliance_rate_mean		0.25
information_compliance_rate_standard_deviation		0
relative_indifference_bound_route_choice_mean		0.1
minimum_travel_time_saving_mean		1
minimum_travel_time_saving_standard_deviation		1
minimum_delay_ratio_for_enroute_switching		3
minimum_delay_seconds_for_enroute_switching		600
minimum_seconds_from_arrival_for_enroute_switching		300

Routing and skimming controls

Name	Unit	Value
enroute_switching_enabled		True
aggregate_routing		False
nario File: C:\Users\jauld\Desktop\Polaris-Amber\Files\5. polaris_model\scenario_run.json		False
time_dependent_routing_weight_shape		2.5
time_dependent_routing_weight_scale		1800
time_dependent_routing_weight_factor		0
historical_results_database_name		bloomington
multimodal_routing		False
multimodal_routing_model_file		MultiModalRoutingModel.json
input_highway_skim_file_path_name		highway_skim_file.bin
input_transit_skim_file_path_name		transit_skim.bin
read_skim_tables		True

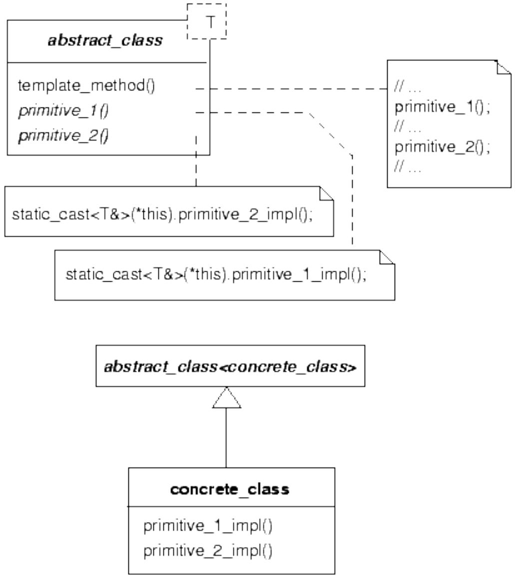
Population synthesizer controls

Parameter externalization

- Parameters for majority of behavior models, network setting, scenario setting are externally configurable through .json
- Added json editor in AMBER
- Remaining models to externalize:
  - Generation, vehicle choice, CAV purchase,…

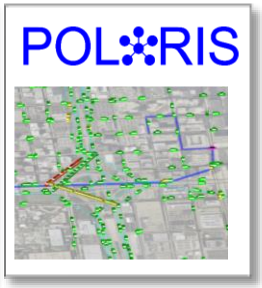
POLARIS Migrated to Linux for HPC

- Goals:
  - POLARIS to be available on both Windows and Linux platforms to support HPC
- Benefits:
  - Cross platform development and execution
  - Improved design patterns for agents
    - Allows designers to implement agents using familiar Object Oriented techniques including Curiously recurring template patterns (CRTP) with facades
    - Requires less meta-programming than before
    - Compiler performs better type checking resulting in fewer runtime errors
    - Same runtime performance on same architecture
- Status:
  - Cross-platform source compiles, links and runs
  - Currently regression testing against previous build to validate new code
  - Next step: adapt code to run on large-scale cluster (i.e. Theta) with scenario manager

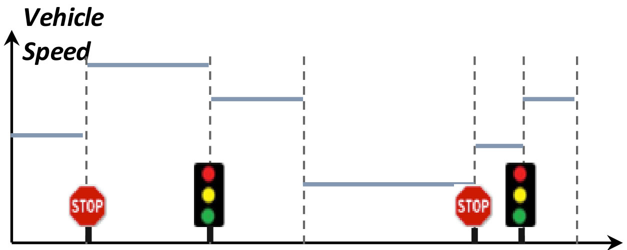


SVTriP Generates Naturalistic Speed Profile from Macroscopic Trip Definition

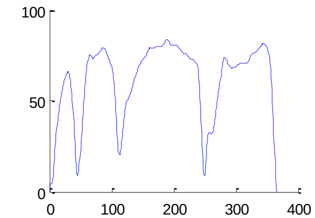
Define trip in a map or generate trip in transportation simulator



Segment-by-segment trip characteristics: speed limit, average speed, stops, etc.



SVTRIP



1 Hz speed profile

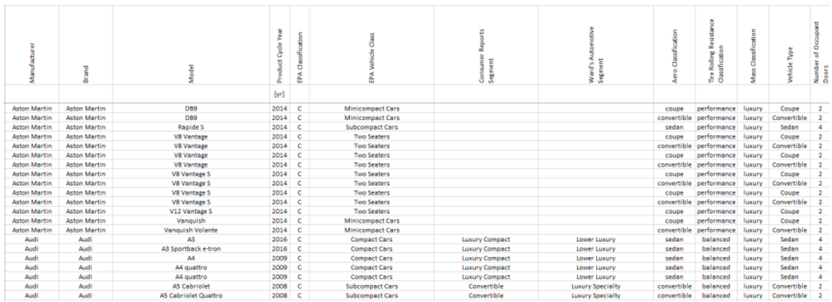
Energy Consumption Simulation (Autonomie)

- Developed interface connecting HERE REST APIs with SVTriP
- Improved robustness and performance: deterministic algorithm for non-convergent situations, situation-specific probability matrices, cost function optimization
- Expanding training datasets to increase the number of applications (Transit buses, class 8 trucks, CAVs)
- Improving core algorithm:
  - – Enhancing source data with road attributes (esp. road class and speed limit) to improve classification
  - – Exploring deep learning as an alternative to Markov chains

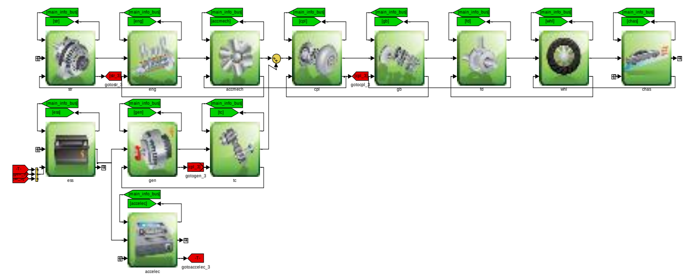
AMBER New Workflows Examples

Initialize Models From Vehicle Technology Database

1 – Select Vehicle(s) from Database (e.g., Ford Focus MY16 6AU...)



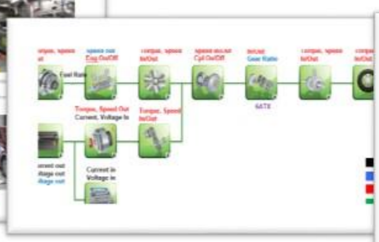
2 – Automatically Initialize Parameters (i.e. Cd, FA, weight, power…) for the Associated Autonomie Vehicle Model



Automated Vehicle Models Development and Validation

1 - Load Vehicle Test Data

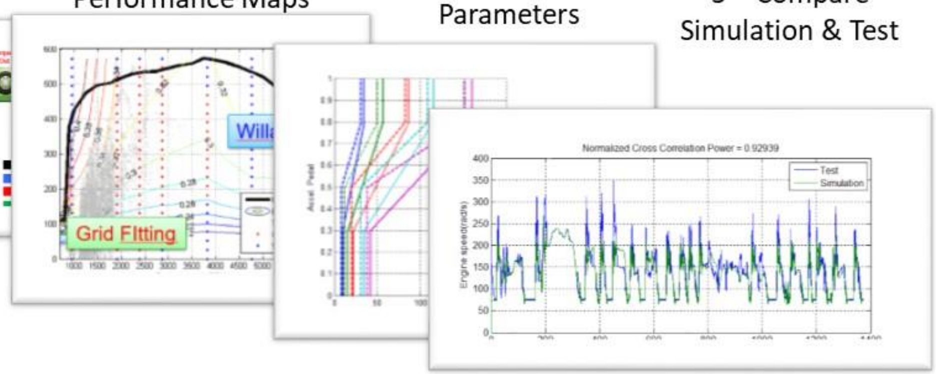
2 – Pre-process Vehicle Test Data



3 – Develop Component Performance Maps

4 – Calibrate Control Parameters

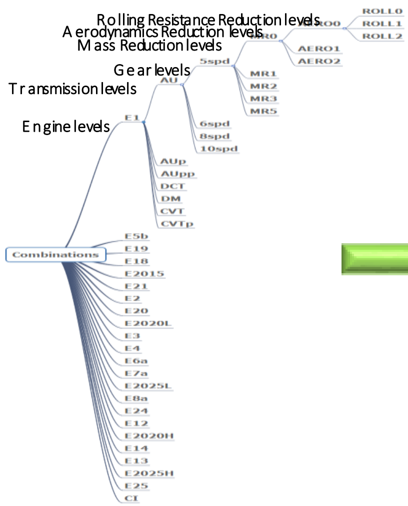
5 – Compare Simulation & Test



2-3% fuel consumption uncertainty for conventional vehicles

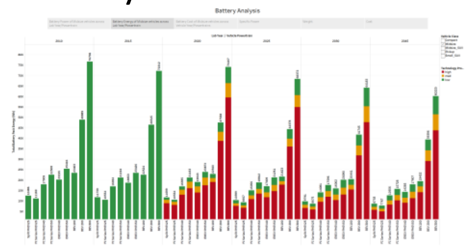
AMBER New Workflows Examples

Launch & Analyze Very Large Number of Simulations



Launch Simulations and Create SQL Database

Tableau Analysis



QA/QC with Technology Database

Transportation Energy Analysis Workflow

1 – Load POLARIS Results (Mobility)

2 – Define Fleet Composition

Fleet

SVTrip (Stochastic Speed Profile Generation)

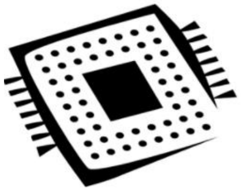
4 – Predict Vehicle Trip Profile for each Agent

3 – Assign Each Vehicle to an Autonomie Model

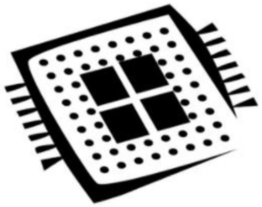
5 – Simulate Energy for Each Agent & Analyze

Options for Computational Efficiency

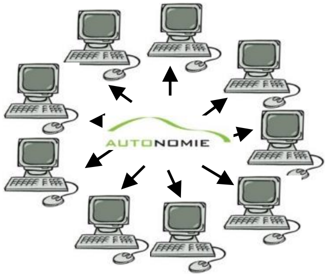
Option #1 –
Run Simulations
w/ Single Core



Option #2 –
Run Simulations
w/ Multi-Core
(run_mpi)



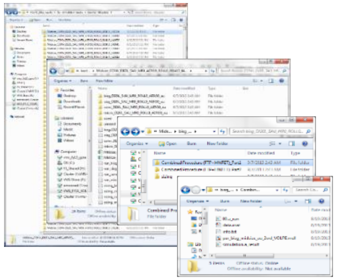
Option #3 –
Run Simulations
w/ Distributed
Computing



Option #1
Run SLK

Option #2
Run Compiled

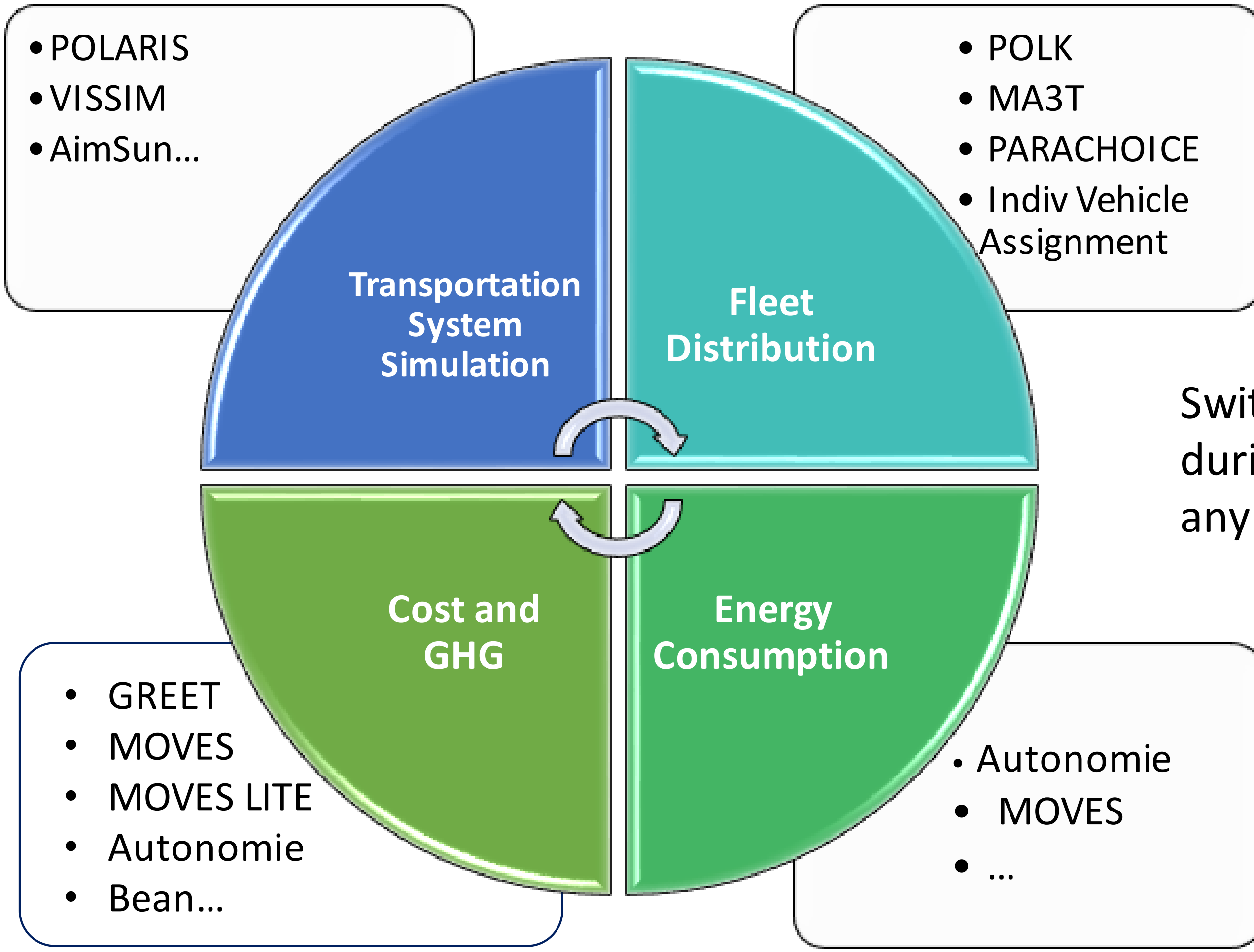
Option #1
Save All Results



Option #2
Save Some Results &
Generate Database

Vision for AMBER Workflows

Smart Mobility Example



Switch any model during any step of any workflow

Response to Previous Year Reviewers' Comments

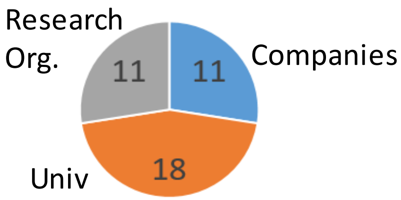
Previous comments were extremely positive except for reviewer #5

Comments from 2017 Annual Merit Review	Response
Reviewer 5 said that including complete models of every vehicle inside a model of fleets or groups of fleets seems like gross overkill for most practical purposes. The reviewer believed the barriers this project is addressing are not well defined, and therefore did not think the project is well designed or feasible	Using average energy consumption values (i.e energy/distance) does not allow to quantify the energy impact of technologies affecting vehicle speed, which most of the Smart Mobility technologies target. Detailed models are also required to predict future technology benefits.
Reviewer 5 opined that there are no examples provided of a specific problem that AMBER would help address	EEMS013 focused on tool development. For example of recent usage for VTO, please refer to EEMS001, EEMS016, EEMS017, EEMS029, EEMS031, EEMS032, EEMS055, VAN023, FT037, ELT189, ACS012, TI070, TI086
Reviewer 5 said that there are no well-defined goals so there is no way to measure progress against those goals.	Goals of the project is to develop models and workflows to support VTO study requirements. The numbers of projects supported directly or indirectly speaks by itself
Reviewer 5 commented that the poster provided very little evidence of collaboration or coordination with any other researchers or institutions that are either involved in similar work or might be users of the product of this work.	Autonomie has been licensed to more than 205 companies worldwide and is used to support major projects funded by the US Government. Argonne has on-going projects with more than 25 organizations.
Reviewer 5 noted that there is some brief mention of meetings with General Motors and Ford, but no names are provided of the people involved and there is no record of the outcome or result of the meetings	If reviewer #5 is from GM or Ford, I will be glad to provide the names.

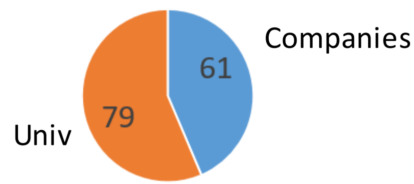
Partnerships and Collaborations

Users Overview (# of Institutions)

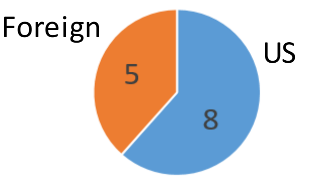
40 Government



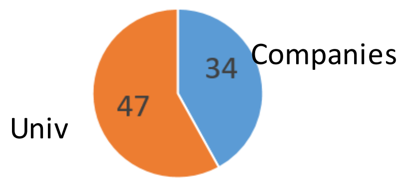
140 Paid Licenses Institutions



13 Classroom



81 New License Requests (Past 12 months)



Main Programs Supported

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

Co-Optimization of Fuels & Engines

GATE

SuperTruck

EcoCAR3 Advanced Vehicle Technology Competition

CAFE Corporate Average Fuel Economy

arpa·e NEXTCAR

Current Project Partners

U.S. Department of Transportation National Highway Traffic Safety Administration

Volpe The National Transportation Systems Center

Washington State University

TARDEC

Federal Transit Administration

Clemson University

ORNL Oak Ridge National Laboratory

City of Chicago

California PATH

IFP Energies nouvelles

Connected Signals

M MTC

Rensselaer

NREL National Renewable Energy Laboratory

Chicago Metropolitan Agency for Planning (CMAP)

Michigan

Auburn University

Institut VeDeCoM

Illinois Institute of Technology

UNSW The University of New South Wales

cta Chicago Transit Authority

Tsinghua University

Carnegie Mellon University

here

George Mason University

CDOT Chicago Department of Transportation

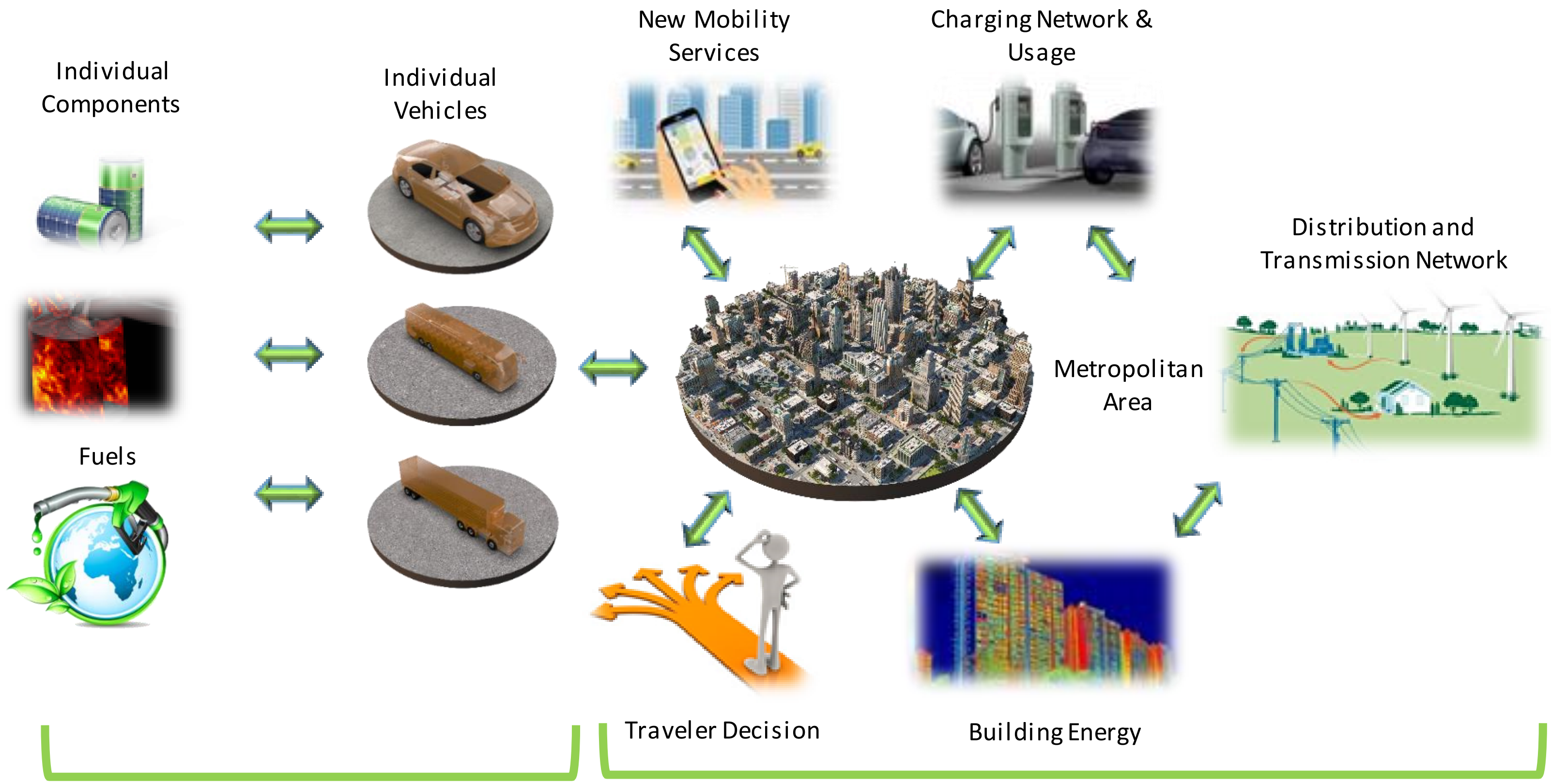
A|M

UIC

Remaining Challenges and Barriers

- Complete new workflows (i.e., Transportation system simulation, transportation energy)
- Continue to improve computational efficiency (i.e., migrate any large scale simulation process to HPC)
- Deploy workflows that do not require any licenses (i.e. no MathWorks licenses) when appropriate
- Expand the current workflow to include additional tools, both commercially available and developed by US Gov funding.
- Develop training curriculum for vehicle electrification and Smart Mobility for classroom usage

Proposed Future Research



Historic VTO Focus

Additional EEMS Focus

Continue to develop and apply tools to estimate mobility and energy impact of new technologies

Summary

- **Key achievements**:
  - Released Autonomie R16 and first AMBER version
  - Developed detailed vehicle technology database for current vehicles
  - Implemented new powertrain configurations and component technologies
  - Validate multiple vehicles using dynamometer test data
  - Significantly expanded capabilities for MD & HD
  - Developed multiple new workflows, including transportation energy workflow
  - Tools supported very large number of studies and user community

- **Next steps**
  - Focus future development to support US DOE VTO and more specifically EEMS
  - Continue to gather new requirements from users to prioritize future activities
  - Continue to provide system simulation for VTO to support R&D portfolio

Technical Backup Slides

AMBER Workflow - Simulate a Single Vehicle

Specific Workflows for Specific needs

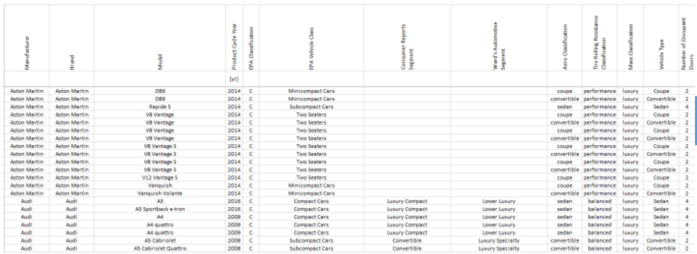
Increased Flexibility / Expertise

	Select Vehicle	Change Parameter	Change Initialization File	Change Model	Select Cycle
Option #1	✓				✓
Option #2	✓	✓			✓
Option #3	✓	✓	✓		✓
Option #4	✓	✓	✓	✓	✓
Option #5…					

AMBER Workflow - Market Analysis

1 – Load Database

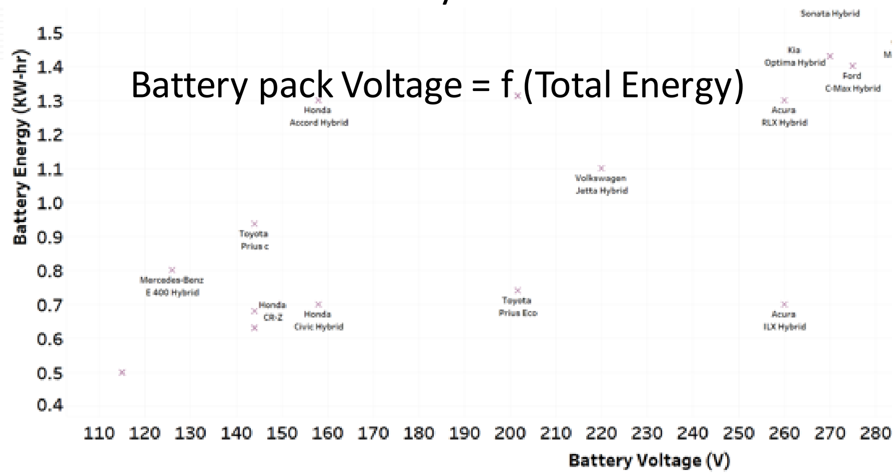
Option #1 – Vehicle Technology Database

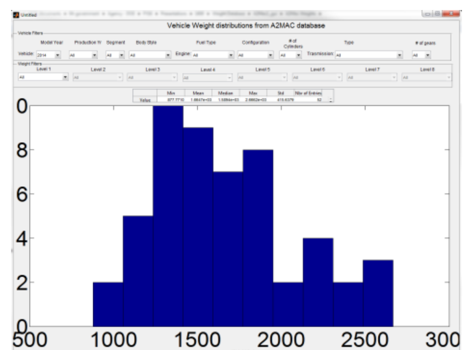


Option #2
A2MAC1

2 – Perform Analysis

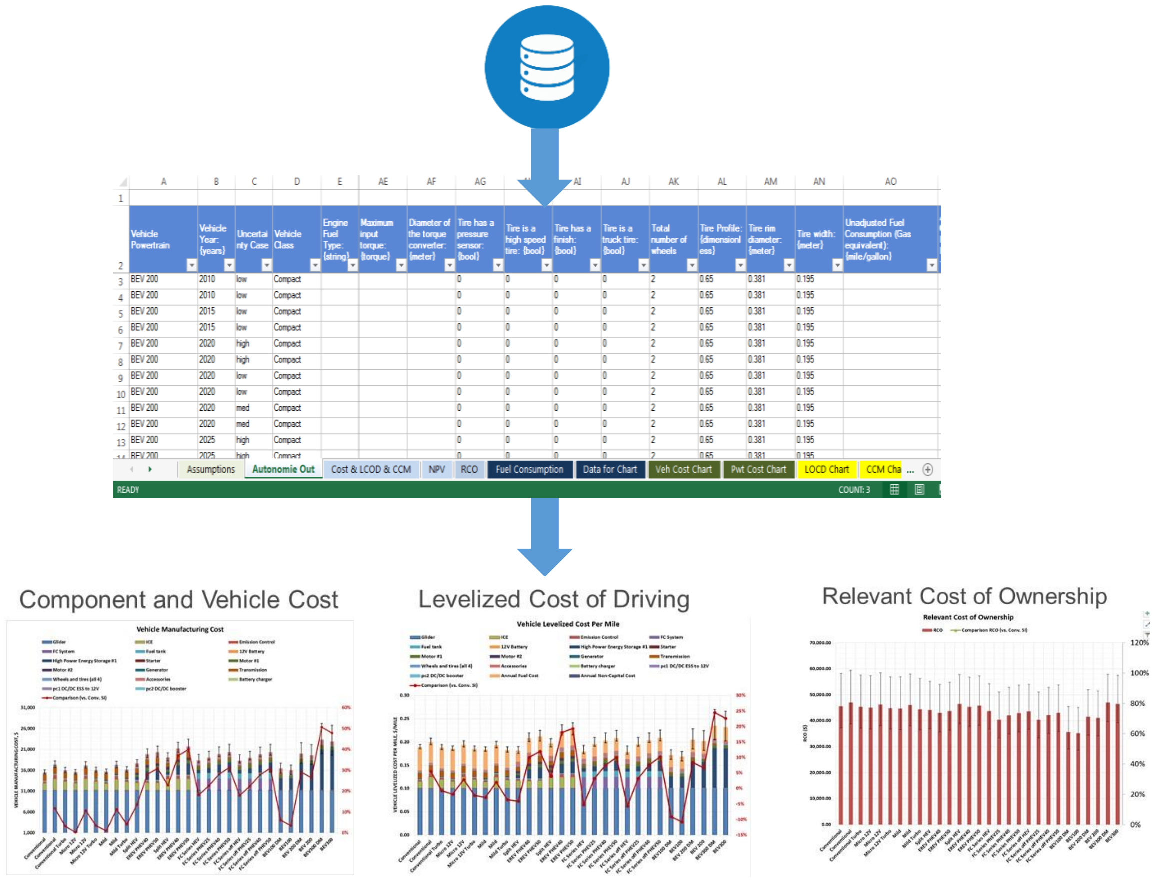
Battery pack Voltage = f (Total Energy)





Component/Vehicle Weight Distribution

AMBER Workflow - Techno-Economic Analysis of Vehicle Technologies



1 – Load Database Generated from Large Number of Simulations

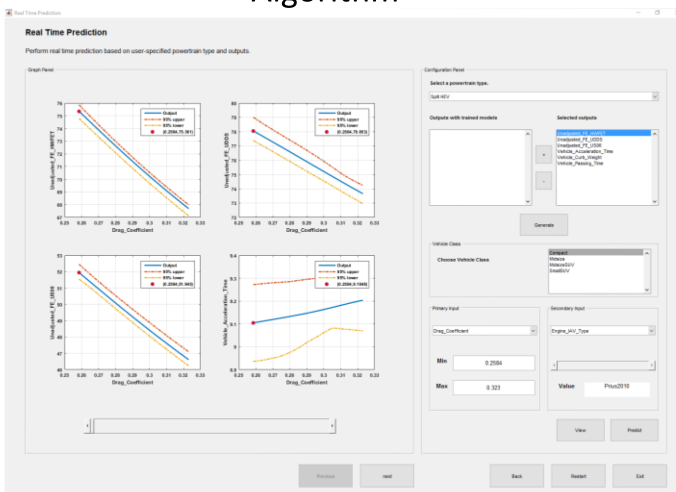
2 – Enter Cost Assumptions (component, vehicle, TCO…)

3 – Analyze Results

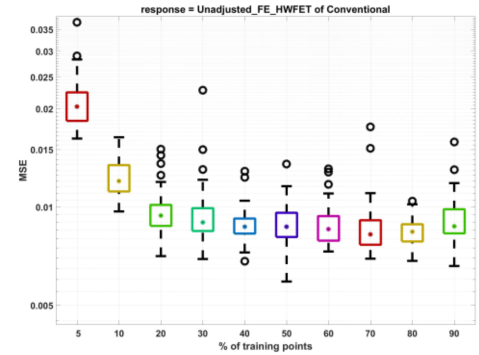
AMBER Workflow - Machine Learning Model Workflow to Assess Energy Impact of Technologies

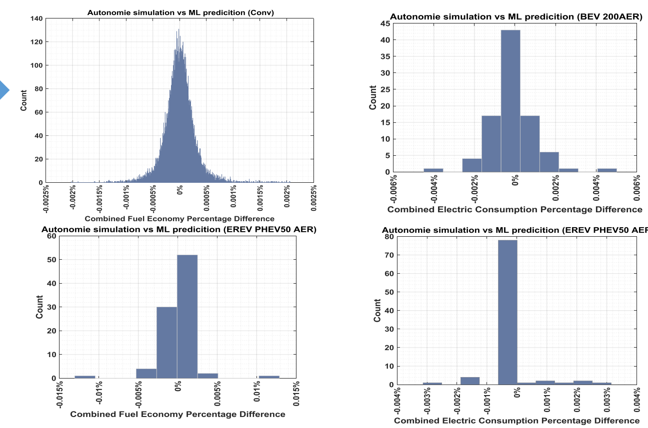
1 – Select Inputs: Actual Measured Data or Simulated Autonomie Results

2 – Launch Machine Learning Model Algorithm



3 – Analyze Accuracy vs Number of Training Points Assessed





4 – Train Model and Analyze Error of the ML

AMBER Workflow - Predict Vehicle Trip Profile from GIS

Trip definition Origin, destination, waypoints


```
%% Route definition
date_route='2017-02-03T09:00:00'; % Some time

% Short route in Chicago
route_coord=[41.91907, -87.681155;
    41.903644,  -87.64266;
    41.895211, -87.637081];
seg_waypts=[41.903644,  -87.64266];

%% Function calls
[route_proc,S_tiles]=calc_route_main(here_app_
    route_coord,date_route,param_calc);
```

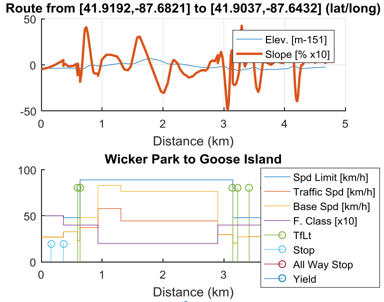
Use Case with HERE Maps

HTTP REST query

Route data and data tiles

Processing
Feature extraction, Data Correction, QC

Target



SVTriP

Naturalistic Speed Trace(s) (+grade)